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Improved Plane-Wave Illumination for the TLM Method

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Indexing Terms

Transmission line matrix, TLM, Modelling, Electromagnetic waves, Huygen's surface

Abstract

An efficient solution to the problems associated with plane wave illumination of a scattering body in a TLM mesh is presented. The solution is equivalent to a partial implementation of the Huygen's surface [1] used in the Time-Domain Finite Difference (TDFD) method, but, additionally, accounts for dispersion effects.

Introduction

The Transmission Line Matrix (TLM) method of numerical electromagnetic analysis using the symmetrical condensed node is well known [2]. It has been widely used to determine scattering from structures under plane wave illumination. However the problems of obtaining an accurate plane wave are not well reported. Here we will address these problems and provide a simple and efficient solution.

When a plane wave is excited in a finite TLM mesh with matched[1] boundaries, the sudden truncation of the mesh causes a second wavefront to be generated at each boundary. This is due mainly to the physical truncation of the wavefront at the boundaries and to a lesser extent to the fact that the boundary does not represent a true radiation boundary condition. In order to demonstrate this a simple Gaussian plane wave was excited in a TLM mesh, with a 10x10 node cross section (Fig. 1), and the field observed for three scenarios (Fig. 2):

1. with the wave propagating in the mesh with asymmetric boundaries as described below – the Gaussian profile is preserved;

2. with no asymmetric boundaries and matched terminations at the edges of the mesh – a considerable negative excursion occurs after the initial Gaussian pulse due to the truncation of the wavefront at the boundaries of the problem;

[1]The transmission lines at the outer surface being terminated in a matched load.

3. with the same 10x10 node plane wave as in 2) in a larger mesh (60x60) – a similar time response occurred showing that the negative excursion is mainly due to the truncation of the wave rather than failure of the boundary in some way.

The problem of plane wave illumination is often overcome using problem boundaries which have a +1 reflection coefficient (magnetic walls) at the edge of the wave parallel to the electric field and –1 reflecting boundaries perpendicular to the electric field. This produces an ideal waveguide in which a plane wave can propagate. However these reflecting walls serve to return waves scattered by the illuminated object to the observation point which interfere with the observation of the direct scattered waves. In order to avoid this the problem space must be made large enough that reflections from the boundaries do not reach the observation point in the time span of the simulation. However this results in an excessively large problem space and may not be possible where a large number of iterations are required.

The implementation of asymmetric boundaries, equivalent to a partial Huygen's surface, proposed here provides an efficient solution to the problems outlined above.

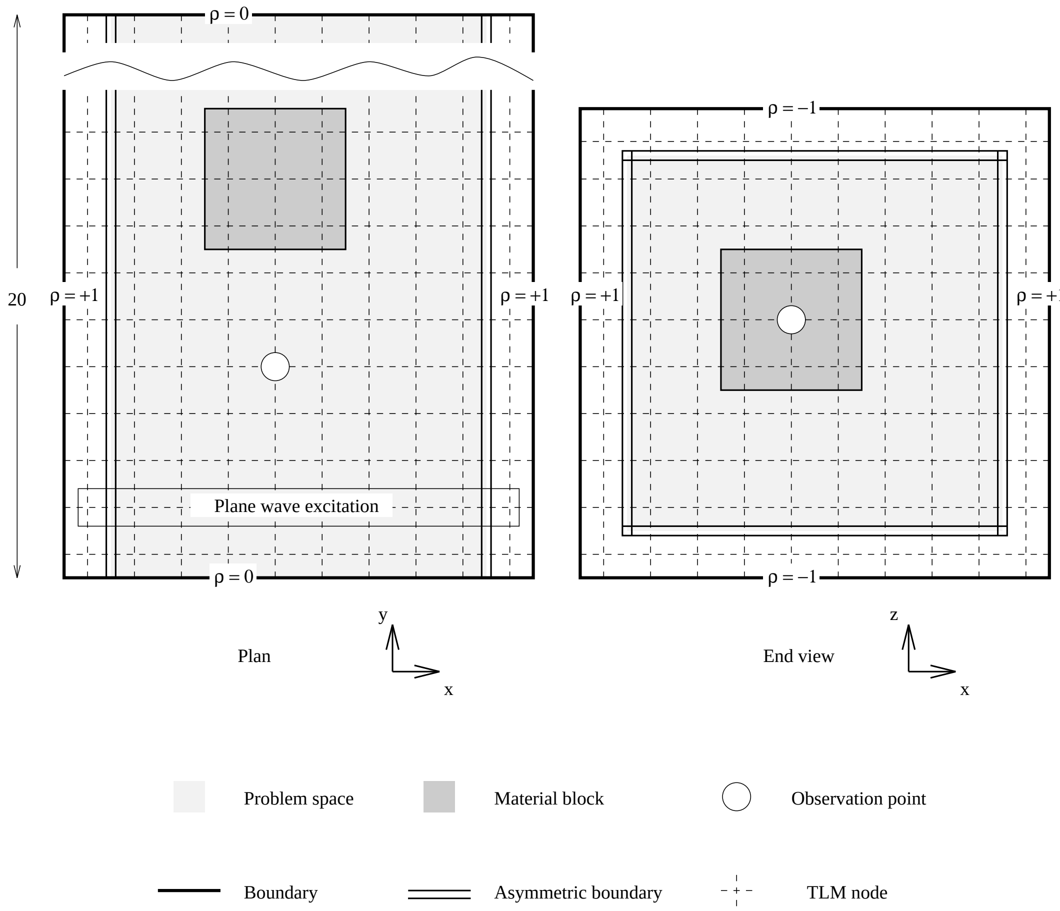

Figure 1: Arrangement of asymmetric boundaries within the TLM mesh.

Implementation

Using a set of simple asymmetric boundaries in the TLM mesh the distortion of the wavefront due to the discontinuity of the plane wave can be removed whilst still maintaining a matched boundary for the scattered field. As shown in Fig. 1 the

TLM mesh is terminated with −1 reflection coefficient boundaries on the faces perpendicular to the electric field of the plane wave, +1 reflection boundaries parallel to the electric field, and matched boundaries on the remaining two faces. Asymmetric boundaries are constructed, as a tube, parallel to the direction of propagation of the plane wave, one mesh unit inside the TLM mesh. The reflection coefficient of the inside faces of the asymmetric boundaries is set to zero (matched) as is the transmission coefficient. This means that the problem space appears to have matched boundaries on all sides for the scattered fields. Also no energy from the inner problem space can reach the outer region between the asymmetric boundaries and the sides of the TLM mesh. The outer faces of the asymmetric boundaries have reflection coefficients identical to the outer boundary which they face and a unity transmission coefficient. Thus a (plane) wave can propagate in the waveguide formed by the asymmetric boundaries and outer surface of the mesh undisturbed by any waves from within the problem space. However if a plane wave is excited across the entire cross section of the TLM mesh (as in Fig. 1) the parts of the wave propagating in the problem space and the outer layer are in time phase and will remain so regardless of any dispersion in the mesh. The energy transmitted from the outer layer to the problem space provides the necessary continuity so that the wave in the problem space is not truncated and thus no spurious wavefronts are generated.

Therefore, by the use of asymmetric boundaries we have achieved propagating conditions for the exciting plane wave as if we had used +/−1 problem space boundaries to create a waveguide capable of sustaining the wave, whilst for scattered fields the problem space has matched boundaries. The method can be shown to be equivalent to a partial implementation of a Huygen's surface as used in the TDFD method.

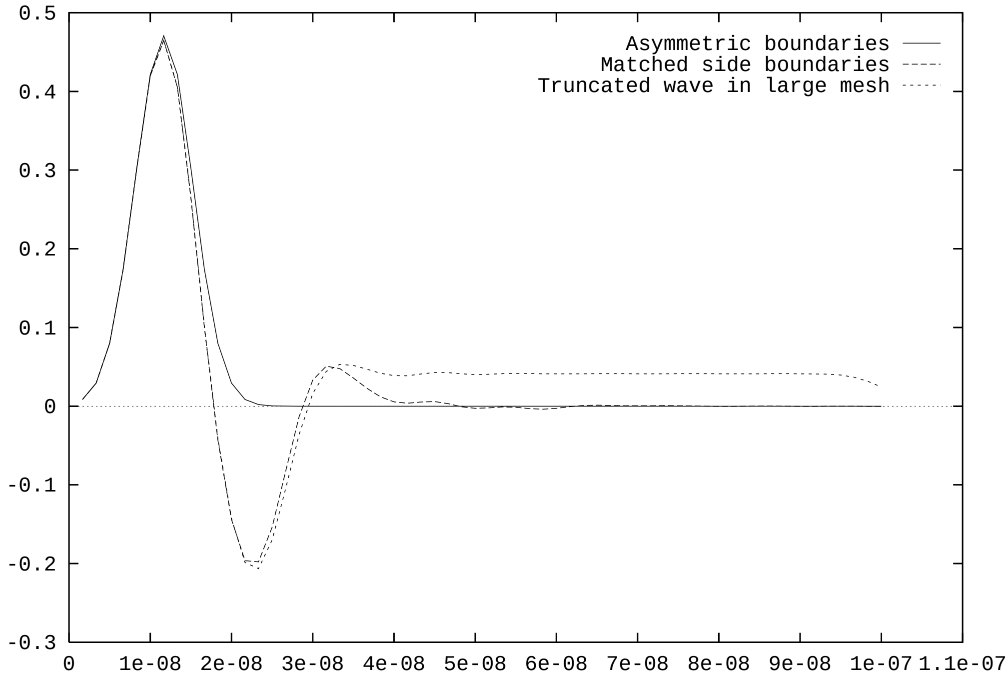

Figure 2: Comparing asymmetric boundaries with zero boundaries in 10x10 cross section mesh and a truncated 10x10 plane wave in 60x60 mesh (no scatterer).

Results

Fig. 2 shows the time history of the fields at the observation point in Fig. 1 for the cases where asymmetric boundaries (partial Huygen's surface) are used, where matched boundaries are used, and where a truncated plane wave in a larger problem space have been used. The Gaussian pulse shape is seen for the first case but in the second two the truncation of the plane wave produces additional wavefronts from the ends of the wave which distort the waveform at the observation point. The case for +/−1 boundaries corresponds exactly to the case with asymmetric boundaries here as there are no scattered fields.

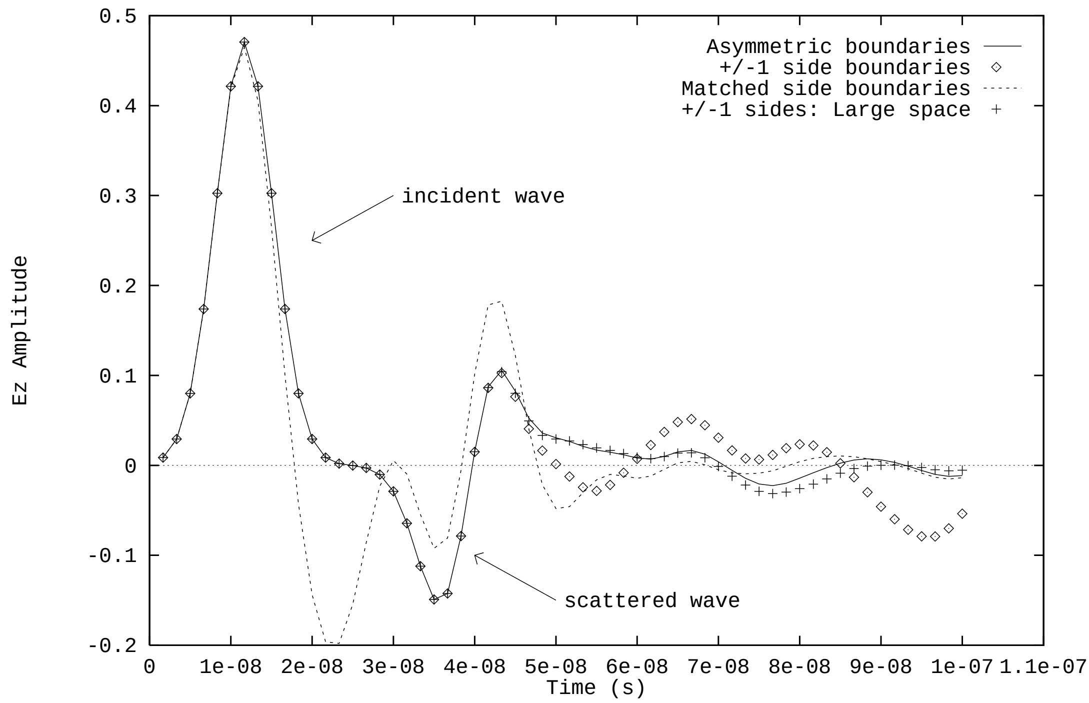

Figure 3: Gaussian pulse plane wave in mesh with scattering object.

Fig. 3 show the time history at the observation point with the scattering object (Fig. 1) present. It can be seen that the use of the partial Huygen's surface gives results (solid line) which correspond very closely to the ideal case (+ points) with +/−1 boundaries used with a very large (60x20x60) mesh size but this is achieved with a small (10x20x10) mesh size. The large mesh size ensures that the reflections from the boundaries do not reach the observation point within the observed time span. For the small mesh size, +/−1 boundaries result (diamonds) in multiple reflections which distort the observation of the scattered field as does the additional wavefront if matched boundaries are used (broken line).

Conclusions

A simple and efficient method of implementing a partial Huygen's boundary in the TLM mesh has been demonstrated. The method allows the use of considerably smaller TLM meshes for scattering problems excited with a plane wave source than previously possible. The method uses the TLM mesh itself to generate the (equivalent of) retarded surface currents for the Huygen's surface and therefore automatic compensation for any dispersion in the mesh is achieved. This also means that the method is suitable for problems using a graded mesh without further modification.

References

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